# SCIENCE

A WEEKLY JOURNAL DEVOTED TO THE ADVANCEMENT OF SCIENCE, PUBLISHING THE OFFICIAL NOTICES AND PROCEEDINGS OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

FRIDAY, NOVEMBER 27, 1908

*CONTENTS*

MSS. intended for publication and books, etc., intended for review should be sent to the Editor of SCIENCE, Garrison-on-Hudson, N. Y.

## *URANIUM AND GEOLOGY—II*

### RADIO-ACTIVE DEPOSITS AND THE INSTABILITY OF THE CRUST

AT the meeting of the British Association held last year at Leicester, I read a note on the thermal effects which might be expected to arise at the base of a sedimentary accumulation of great thickness due to the contained radium.

The history of mountain-building has repeated itself many times: ages of sedimentation, with attendant sinking of the crust in the area of deposition, then upheaval, folding up of the great beds of sediment, and even their over-thrusting for many miles. So that the mountain ranges of the world are not constituted from materials rising from below, save in so far as these may form a sustaining core, but of the slowly accumulating deposits of the ages preceding the upheaval.

The thickness of collected sediments involved in these great events is enormous, and although uncertainty often attends the estimation of the aggregate depths of sedimentation, yet when we consider that unconformities between the deposits of succeeding eras represent the removal of vast masses of sediment to fresh areas of deposition, and often in such a way as to lead to an under-estimate of the thickness of deposit, the observations of the geologist may well indicate the minor and not the major limit. Witness the mighty layers of the Huronian, Animikean and Keweenawan ages where deposits measured in miles of thickness are succeeded by unrecorded intervals of time, in which we know with certainty that the tireless forces of denudation labored to undo their former work. Each era represents a slow and measured pulse in the earth's crust, as if the overloading and sinking of the surface materials induced the very conditions required for their reelevation. Such events, even in times when the crust was thinner and more readily disturbed than it is now, must have taken vast periods of time. The unconformity may represent as long a period as that of accumulation. In these Proterozoic areas of America, as elsewhere on the globe and throughout the whole of geological history, there has been a succession in time of foldings of the crust always so located as to uplift the areas of sedimentation, these upheavals being sundered by long intervals during which the site of sedimentation was transferred and preparation made for another era of disturbance. However long deferred, there seems to be only the one and inevitable ending, inducing a rhythmic and monotonous repetition surely indicative of some cause of instability attending the events of deposition.

The facts have been impressively stated by Dana:

> A mountain range of the common type, like that to which the Appalachians belong, is made out of the sedimentary formations of a long preceding era; beds that were laid down conformably, and in succession, until they had reached the needed thickness; beds spreading over a region tens of thousands of square miles in area. The region over which sedimentary formations were in progress in order to make, finally, the Appalachian range, reached from New York to Alabama, and had a breadth of 100 to 200 miles, and the pile of horizontal beds along the middle was 40,000 feet in depth. The pile for the Wahsatch Mountains was 60,000 feet thick, according to King. The beds for the Appalachians were not laid down in a deep ocean, but in shallow waters, where a gradual subsidence was in progress; and they at last, when ready for the genesis, lay in a trough 40,000 feet deep, filling the trough to the brim. It thus appears that epochs of mountain-making have occurred only after long intervals of quiet in the history of a continent.

The generally observed fact that the deposition of sediments in some manner involves their ultimate upheaval has at various times led to explanations being offered. I think I am safe in saying that although the primary factor, the compressive stress in a crust which has ceased to fit the shrinking world within it, has probably been correctly inferred, no satisfactory explanation of the connection between sedimentation and upheaval has been advanced. The mere shifting upwards of the isogeotherms into the deposits, advanced as a source of local loss of rigidity by Babbage and Herschel, need not involve any such loss so long as the original distance of the isogeotherms from the surface is preserved.

We see in every case that only after great thickness of sediments has accumulated is the upheaval brought about. This is a feature which must enter as an essential condition into whatever explanation we propose to offer.

Following up the idea that the sought-for instability is referable to radio-thermal actions, we will now endeavor to form some approximate estimate of the rise of temperature which will be brought about at the base of such great sedimentary accumulations as have gone towards mountain-building, due to the radium distributed throughout the materials.

The temperature at the base of a feebly radio-active layer, such as an accumulation of sediments, is defined in part by radio-active energy, in part by its position relative to the normal isogeotherms, whether these latter are in turn due to or influenced by radio-thermal supplies or not. It is convenient, and I think allowable, to consider these two effects separately, and deal with them as if they were independent, the resultant state being obtained by their summation.

In dealing with the rise of temperature at the base of a radio-active layer we arrive at an expression which involves the square of the depth. This is a very important feature in the investigation, and leads to the result that, for a given amount of radium, diffuse distribution through a great depth of deposit gives rise to a higher basal temperature than a more concentrated distribution in a shallower layer.

But this will not give us the whole effect of such a deposit. Another and an important factor has to be taken into account. We have seen that the immediate surface rocks are of such richness in radium as to preclude the idea that a similar richness can extend many miles inward.

Now, it is upon this surface layer that the sediments are piled, and as they grow in thickness this original layer is depressed deeper and deeper, yielding under the load until at length it is buried to the full depth of the overlying deposit. This slow and measured process is attended by remarkable thermal effects. The law of the increase of temperature with the square of the depth comes in, and we have to consider the temperature effect not merely at the base of the deposited layer, but that due to the depression and covering over of the radium-rich materials upon which the sediments were laid down.

The table which follows embodies an approximate statement of the thermal results of various depths of deposit supposed to collect under conditions of crustal temperature such as prevail in this present epoch of geological history.

I have deferred to the conclusion of this address an account of the steps followed in obtaining the above results. It is clearly impossible, within the limited time allotted to me, to make these quite clear. It must suffice here merely to explain the significance of the figures.

| Thickness of Sedimentary Deposit Kilometers | Resulting Rise of Isogeotherms Kilometers | Weakening of Earth's Crust as Defined by the Rise of the Geotherm at 40 Kilometers Kilometers |
|---|---|---|
| 6 | 7.4 | 40 to 32.6 |
| 8 | 10.2 | 40 to 29.8 |
| 10 | 13.3 | 40 to 26.7 |
| 12 | 16.7 | 40 to 23.3 |
| 14 | 20.4 | 40 to 19.6 |

The first column gives the depth of sedimentary deposit supposed to be laid down on the normal radio-active upper crust of a certain assumed thickness and radio-activity. From the rise of temperature which occurs at the base of this crust (due to the radio-activity, not only of the crust, but of the sediments) the results of the second column are deduced, the gradient or slope of temperature prevailing beneath being derived from the existing surface gradients corrected for the effects of the radio-thermal layer. The third column is intended to exhibit the effect of this shift of the geotherms in reducing the strength of the crust. I assume that at a temperature of 800° the deep-seated materials lose rigidity under long-continued stress. The estimated depth of this geotherm is, on the assumptions, about 40 kilometers. The upward shift of this geotherm shows the loss of strength. Thus in the case of a sedimentary accumulation of 10 kilometers the geotherm defining the base of the rigid crust shifts upwards by 13 kilometers, so that there is a loss of effective section to the amount of 30 per cent.

As regards the claims which such figures have upon our consideration, my assumptions as to thickness and radio-activity of the specially rich surface layer are, doubtless, capable of considerable amendment. It will be found, however, that the assumed factors may be supposed to vary considerably, and yet the final results prove such as, I believe, can not be ignored. Indeed, those who are in the way of making such calculations, and who enter into the question, will find that my assumptions are not specially favorable, but are, in fact, made on quite independent grounds. Again, a certain class of effects has been entirely left out of account, effects which will go towards enhancing, and in some cases greatly enhancing, the radio-thermal activity. I refer to the thickening of the crust arising from tangential pressure, and, at a later stage, the piling up and overthrusting of mountain-building materials. In such cases the temperature of the deeper parts of the thickened mass must still further rise under the influence of the contained radium. These effects only take place, indeed, after yielding has commenced, but they add to the element of instability which the presence of the accumulated radio-active deposits occasions, and doubtless increase thermal metamorphic actions in the deeper sediments, and result in the refusion of rocks in the upper part of the crust.[19]

The effect of accumulated sediment is thus necessarily a reduction in the thickness of that part of the upper crust which is capable of resisting a compressive stress. Over the area of sedimentation, and more especially along the deepest line of synclinal depression, the crust of the globe for a period assumes the properties belonging to an earlier age, yielding up some of the rigidity which was the slow inheritance of secular cooling. Along this area of weakness—from its mode of formation generally much elongated in form—the stressed crust for many hundreds, perhaps thousands, of miles finds relief, and flexure takes place in the only possible direction; that is, on the whole upwards. In this way the prolonged anticline bearing upwards on its crest the whole mass of deposits is formed, and so are born the mountain ranges in all their diversity of form and structure.

We have in these effects an intervention of radium in the dynamics of the earth's crust, which must have influenced the entire history of our globe, and which, I believe, affords a key to the instability of the crust. For after the events of mountain-building are accomplished, stability is not attained, but in presence of the forces of denudation the whole sequence of events has to commence over again. Every fresh accession of snow to the firn, every passing cloud contributing its small addition to the torrent, assists to spread out once more on the floor of the ocean the heat-producing substance. With this rhythmic succession of events appear bound up those positive or negative movements of the strand which cover and uncover the continents, and have swayed the entire course of evolution of terrestrial life.

*Oceanic Deposits.*—The displacements of the crust which we have been considering are now known to be by no means confined to the oceanic margins. The evidence seems conclusive that long-continued movements have been in progress over certain areas of the sea floor, attended with the formation of those numerous volcanic cones upon which the coral island finds foundation. Here there are plainly revealed signs of instability and yielding of the crust (although, perhaps, of minor intensity) such as are associated with the greater movements which terminate in mountain-building. I think it will be found, when the facts are considered, that we have here

---

[19] Professor C. Schmidt (Basel) has recently given reasons for the view that the Mesozoic schists of the Simplon at the period of their folding were probably from 15,000 to 20,000 meters beneath the surface (*Ec. Geol. Helvetiæ*, Vol. IX., No. 4, p. 590). As another instance consider the compression of the Laramide range (Dawson, *Bull. Geol. Soc. Am.*, XII., p. 87).

phenomena continuous with those already dealt with, and although the conditional element of a sufficient sedimentary accumulation must remain speculative, the evidence we possess is in favor of its existence.

One of the most interesting outstanding problems of deep-sea physiography is that of the rates of accumulation of the several sorts of deposit. In the case of the more rapidly collecting sediments there seems no serious reason why the matter should not be dealt with observationally. I hope it may be accomplished in our time. For my present purpose I should like to know what may or may not be assumed in discussing the accumulation of radio-active sediments on the ocean floor.

As regards the rate of collection of the non-calcareous deposits, the nearest approach to an estimate is, I think, to be obtained from the exposed oceanic deposits of Barbados. In the well-known paper of Jukes Brown and Harrison[20] on the geology of that island, it is shown that the siliceous radiolarian earths and red clays aggregate to a thickness of about 300 feet. These materials are true oceanic deposits, devoid of terrigenous substances. They collected very probably during Pliocene and, perhaps, part of Pleistocene times. Now, there is evidence to lead us to date the beginning of the Pliocene as anything from one million to three million years ago. The mean of these estimates gives a rate of collection of 5 millimeters in a century. This sounds a very slow rate of growth, but it is too fast to be assumed for such deposits generally. More recent observations might, indeed, lead us to lengthen the period assigned to the deposition of these oceanic beds; for if, following Professor Spencer,[21] we ascribe their deposition to Eocene times, a less definite time-interval is indicated; but the rate could hardly have been less than 3 millimeters in a century. The site of the deposit was probably favorable to rapid growth.

We have already found a maximum limit to the average thickness of true oceanic sediments; and such as would obtain over the ocean floor if the rate of collection was everywhere the same and had so continued during the past. If there is one thing certain, however, it is that the rates of accumulation vary enormously. The 1,200 or 1,500 feet of chalk in the British Cretaceous, collected in one relatively brief period of submergence, would alone establish this. Huxley inferred that the chalk collected at the rate of one inch in a year. Sollas showed that the rate was more probably one inch in forty years. Sir John Murray has advanced evidence that in parts of the Atlantic the cables become covered with *Globigerina* ooze at the rate of about ten inches in a century. Finally, then, we must take it that the fair allowance of one seventh of a mile may be withheld in some areas and many times exceeded in others.

Now it is remarkable that all the conditions for rapid deposition seem to prevail over those volcanic areas of the Pacific from which ascend to the surface the coral islands—abundant pelagic life and comparatively shallow depths. Indeed, I may remind you that the very favorable nature of the conditions enter into the well-known theory of coral island formation put forward by Murray.

The islands arise from depths of between 1,000 and 2,000 fathoms. These areas are covered with *Globigerina* ooze having a radio-activity of about 7 or 8. The deeper-lying deposits around—red clay and radiolarian ooze—show radio-activities up to and over 50. From these no volcanic islands spring.

These facts, however, so far from being

---

[20] *Q. J. G. S.*, XLVIII., p. 210.

[21] *Ibid.*, LVIII., pp. 354 ff.

opposed to the view that the radio-activity and crustal disturbance are connected, are in its favor. For while those rich areas testify to the supply of radio-active materials, the slow rate of growth prevailing deprives those deposits of that characteristic *depth* which, if I may put it so, is of more consequence than a high radio-activity. For the rise in temperature at the base of a deposit, as already pointed out, is proportional to the square of the thickness; in reality the dilution of the supplies of uranium which reach the calcareous oozes flooring the disturbed areas is a necessary condition for any effective radiothermal actions.

It might appear futile to consider the matter any closer where so little is known. But in order to give an idea of the quantities involved I may state that, if my calculations are correct, a rate of deposit comparable with that of the chalk prevailing for ten million years would, on assumptions similar to those already explained when discussing the subject of mountain-building, occasion a rise of the deeper isogeotherms by from 20 to 30 per cent. of their probable normal depth.

In making these deductions as to the influence of radium in sedimentary deposits, I have so far left out of consideration the question of the time which must elapse in order that the final temperature-rise in the sediments must be attained. The question we have to answer is: Will the rate of rise of temperature due to radium keep pace with the rate of deposition, or must a certain period elapse after the sedimentation is completed to any particular depth, before the basal temperature proper to the depth is attained?

The answer appears to be, on an approximate method of solution, that for rates of deposition such as we believe to prevail in terrigenous deposits—even so great as one foot in a century, and up to depths of accumulation of 10 kilometers and even more—the heating waits on the sedimentation. Or, in other words, there is thermal equilibrium at every stage of growth of the deposit; and the basal temperature due to radioactive heating may at any instant be computed by the conductivity equation. For accumulations of still greater magnitude the final and maximum temperature appears to lag somewhat behind the rate of deposition.

From this we may infer that the great events of geological history have primarily waited upon the rates of denudation and sedimentation. The sites of the terrigenous deposits and the marginal oceanic precipitates have many times been convulsed during geological time because the rates of accumulation thereon have been rapid. The comparative tranquility of the ocean floor far removed from the land may be referred to the absence of the inciting cause of disturbance. If, however, favorable conditions prevail for such a period that the local accumulations attain the sufficient depth, here, too, the stability must break down and the permanency be interrupted.

Upheaval of the ocean floor, owing to the laws of deep-sea sedimentation, should be attended with effects accelerative of deposition—a fact which may not be without influence. But although ultimately sharing the instability of the continental margins, the cycle of change is tuned to a slower periodicity. From the operation of these causes, possibly, have come and gone those continents which many believe to have once replaced the wastes of the oceans, and which with all their wealth of life and scenic beauty have disappeared so completely that they scarce have left a wreck behind. But those forgotten worlds may be again restored. The rolled-up crust of the earth is still rich in energy borrowed from earlier times, and the slow but mighty influences of denudation and deposition are forever at work. And so, perchance, in some remote age the vanished Gondwâna Land, the lost Atlantis, may once again arise, the seeds of resurrection even now being sown upon their graves from the endless harvests of pelagic life.

JOHN JOLY

---

## *REPORT OF THE INTERNATIONAL CONFERENCE ON ELECTRICAL UNITS AND STANDARDS, 1908*

THE report shows that delegates were present from 21 countries, and also from the following British dependencies, namely, Australia, Canada, India and the Crown Colonies.

The total number of delegates to the conference was 43, and their names are set out in schedule A. The conference and its technical committee each held five sittings. As a result of its deliberations, the conference adopted the resolutions and specifications set out in schedule B, and requested the delegates to lay them before their respective governments with a view to obtaining uniformity in the legislation with regard to electrical units and standards.

The conference recommends the use of the Weston normal cell as a convenient method of measuring both electromotive force and current when set up under the conditions specified in schedule C.

In cases in which it is not desired to set up the standards provided in the resolutions of schedule B, the conference recommends the following as working methods for the realization of the international ohm, the ampere and the volt:

1. *For the International Ohm.*—The use of copies, constructed of suitable material and of suitable form and verified from time to time, of the international ohm, its multiples and sub-multiples.

2. *For the International Ampere.*—(*a*) The measurement of current by the aid of a current balance standardized by comparison with a silver voltameter; or

(*b*) The use of a Weston normal cell whose electromotive force has been determined in terms of the international ohm and international ampere, and of a resistance of known value in international ohms.

3. *For the International Volt.*—(*a*) A comparison with the difference of electrical potential between the ends of a coil of resistance of known value in international ohms, when carrying a current of known value in international amperes; or

(*b*) The use of a Weston normal cell whose electromotive force has been determined in terms of the international ohm and the international ampere.

The duty of specifying more particularly the conditions under which these methods are to be applied has been assigned to the permanent commission, and, pending its appointment, to the scientific committee, to be nominated by the president (see schedule D), who will issue a series of notes as appendix to this report.

The conference has considered the methods that should be recommended to the governments for securing uniform administration in relation to electrical units and standards, and expresses the opinion that the best method of securing uniformity for the future would be by the establishment of an international electrical laboratory with the duties of keeping and maintaining international electrical standards. This laboratory to be equipped entirely independently of any national laboratory.

The conference further recommends that action be taken in accordance with the scheme set out in schedule D.

### SCHEDULE A.—LIST OF COUNTRIES AND DELEGATES

America (United States).—Dr. S. W. Stratton; Dr. Henry S. Carhart; Dr. E. B. Rosa.

Austria.—Dr. Viktor Edler von Lang; Dr. Ludwig Kusminsky.

Belgium.—Professor Eric Gérard; M. Clement.

Brazil.—Mr. L. Weiss.

Chile.—Don Victor Eastman.

Colombia.—Don Jorge Roa.

Denmark and Sweden.—Professor S. A. Arrhenius.

Ecuador.—Sr. Don Celso Nevares.